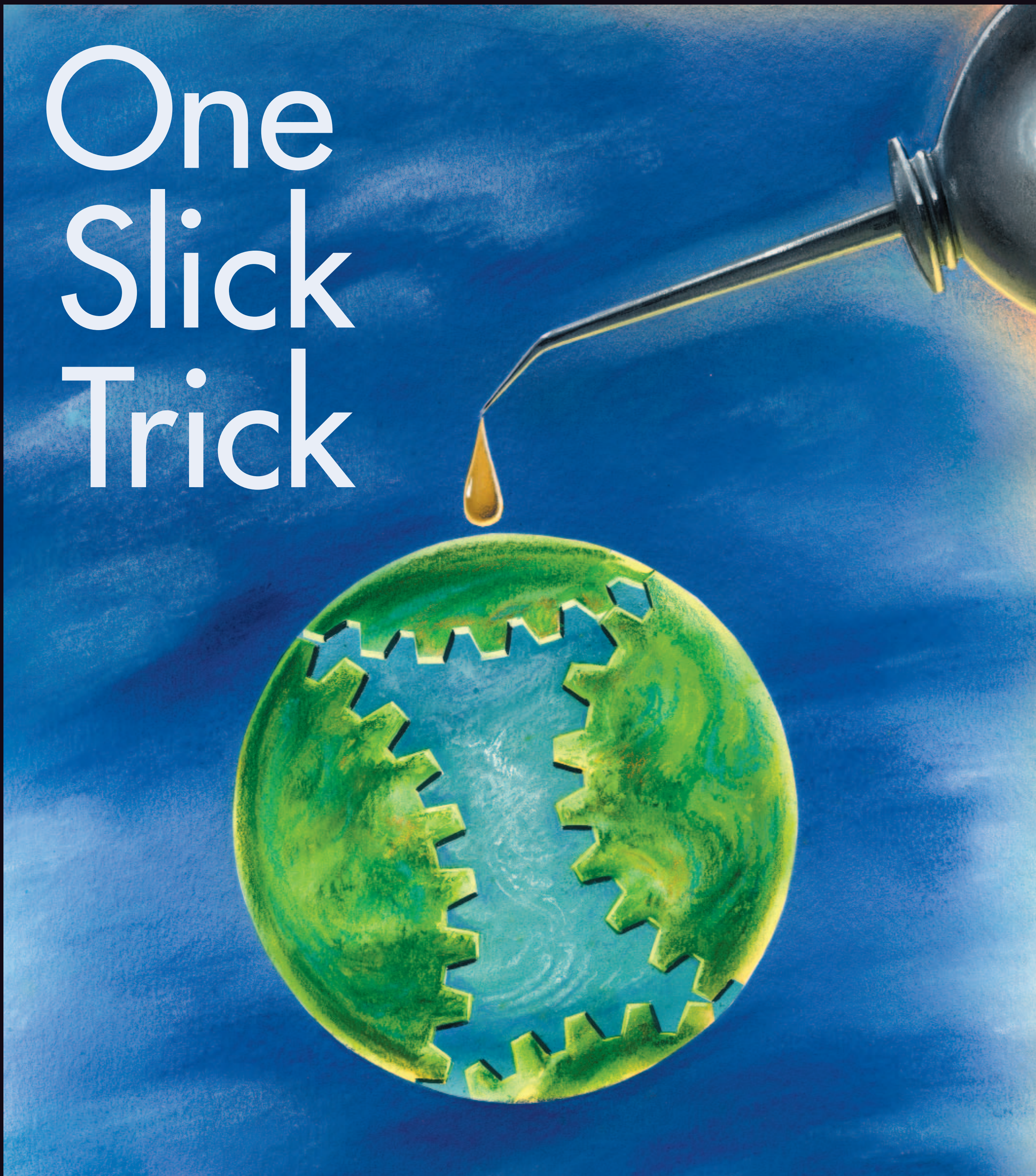
One Slick Trick



Building a Better Biolubricant

Dick Palulian

Pollution from petroleum invades all corners of the environment. Sometimes it comes in floods: tanker ships run aground, pipelines breach, oil rigs catch on fire. But more often it comes in dribbles and spurts, as droplets of oil expelled from the tailpipes of lawn mowers and watercraft, as traces of grease washed free from hydroelectric dams or flung from lubricated train tracks, as gallons of oil trickling from cracked electrical transformers, or as fluid spurting from ruptured hydraulic lines. In 2000, the most recent year for which there are figures, about 2.5 billion gallons of petroleum-based lubricants were sold in the United States alone, according to the National Petrochemical and Refiners Association, based in Washington, D.C. Of that 2.5 billion gallons, several studies have shown that 30–40% escapes into the environment through such routes as spills, leaks, and evaporation.

Until the turn of the last century, animal fats and plant oils were the sources for virtually all lubricants. According to Joseph Perez, a chemical engineer and senior research scientist at Pennsylvania State University in University Park, vegetable oils actually lubricate better than petroleum products—they are naturally more slippery, and they also are more polar, meaning they cling better to metal parts. But the mid-1800s brought the discovery of ways to drill for oil that made petroleum lubricants readily available, and in the 1890s mass production of automobiles began, creating an ever-growing demand for petroleum products. The result was a rapidly expanding infrastructure for extracting crude oil and a drive to create petroleum-based lubricants as well. Petroleum products—which have become cheaper to produce and sell than vegetable oils, and which oxidize less readily—have dominated the market ever since.

The last decade, however, has seen the rise of a new class of lubricants made from renewable resources, and that are less environmentally hazardous and safer for human contact than petroleum-based fluids. These new oils, greases, and industrial fluids are derived from common plant products such as soybeans, sunflower seeds, and canola (or, in Europe, its close relative rapeseed). And in a new twist on an old idea, updated technologies are allowing scientists to develop biobased lubricants that are more stable than their predecessors. The United States lags about 10 years behind Scandinavia and Germany in work on biolubricants, but U.S. companies—some large and established, others small startups—are entering the field with a wide assortment of products that have appeared in applications ranging from the elevators in the Statue of Liberty to Canadian hydroelectric dams to pole-mounted transformers in northern California.

The Good, the Bad, and the Oily

According to Lou Honary, director of the Agriculture-Based Industrial Lubricants (ABIL) research group at the University of Northern Iowa in Waverly (by most accounts the epicenter of U.S. biolubricant research), the U.S. Department of Agriculture has coined the term "biobased" to refer to a product that has a minimum of 51% biomaterial, and is planning to label selected products as "biobased" for use by federal purchasers. There are several executive orders that pertain to biobased lubricants. Perhaps most important is Executive Order 13134 and its accompanying executive memorandum, which in 1999 called for the tripling of the federal government's use of biobased products by 2010. Another important piece of legislation is the Farm Bill that President George W. Bush signed on 13 May 2002, which includes provisions meant to increase the amount of biobased materials that federal agencies purchase. The law also provides $1 million per year for five years for the testing of biobased products.

For many of the emerging markets for biobased lubricants, the appeal is that the products are kinder to the environment than their petroleum-based counterparts. "The main benefit is that if there is any kind of incidental spill—the leakage of a pipe or an inadvertent spill of a drum of it while being brought out on location—[biobased oils] are readily biodegradable and nontoxic or very low toxicity," says Luis del Valle, global marketing director for Cargill Industrial Oils and Lubricants of Minneapolis, Minnesota, the country's largest producer of biolubricants. "So that means they're much safer for both soil and water."

Vegetable oils are also plentiful. About 6.2 billion gallons of soybean oil alone is produced each year worldwide, and about half of that originates in the United States, says Honary. That would appear to be enough to replace petroleum-based fluids, but there's a catch: most of that oil is already used as cooking oil or in food. However, Honary says, U.S. farmers have the capacity to grow more oilseeds than buyers want. If biobased lubricants grow to become a significant portion of the industrial fluids market, farmers will need to grow more oilseeds. And that alone, he says, is a good reason for state and federal governments to promote biobased products. Currently, he says, the nation's farmers produce so many soybeans that the price is forced down to not much more than it costs to grow them. New markets would mean higher prices for farmers who now are barely getting by.

Although biobased products do hold certain natural advantages over petroleum fluids, their shortcomings are what allowed mineral oils to capture and keep the bulk of the lubricant market. Compared to petroleum-based fluids, vegetable oils thicken too much at temperature extremes because they oxidize readily. "Oxidation is one of the processes that deteriorates your lubricant, whether it's in the engine of your car, your boat, or your vehicle hydraulic system," Perez explains. "Oxidation is the interaction between oxygen and the lubricant molecules. The higher the temperature, the more reactive they are. Depending on the nature of the lubricant, you get undesirable effects such as viscosity increases and acid number increases, all of which could cause wear and corrosion."

All vegetable oils consist of triglyceride molecules, which may contain one, two, or three double bonds. If exposed to oxygen at high temperatures, the molecules oxidize easily and form bonds, causing the fluid to increase in viscosity or even form a gel. At low temperatures, as well, the molecules clump together and crystallize, increasing viscosity. "You don't want too many double bonds in the oil," says Sevim Erhan, research leader for the U.S. Department of Agriculture Oil Chemical Research group in Peoria, Illinois. The more double bonds you have, the more susceptible they are to oxidation, she says; then, with oxygen present, the stability will be limited.

Price is another issue. Biobased products usually cost several times more than their petroleum-based counterparts. The

Droplets without drilling. Plants such as (clockwise from top left) soybeans, meadowfoam, and sunflowers offer a source of cleaner, more sustainable oil to be made into various types of lubricants.

Clockwise from bottom: Cargill Industrial Oils and Lubricants; Cargill Industrial Oils and Lubricants; Christopher Christie

relationship between the prices for bio-oils and petroleum oils is dynamic and complex, however. As demand for biobased lubricants increases and prices rise, the ratio of the prices of biobased and petroleum-based lubricants would increase if all other factors, such as the cost of producing bio-oils and the price of crude oil, remained constant. But as production increases, Perez says, economies of scale will drive down the cost of biolubricants.

Now We're Cooking

Oils that can resist oxidation are less likely to form deposits, sludge, and corrosive by-products and are less susceptible to viscosity variations. That's why much of the work on biobased lubricants is directed toward finding ways to minimize their tendency to oxidize. As with petroleum products, chemical processes and closely guarded combinations of additives are used to improve performance. Some of these chemical processes alter the molecules to disturb their symmetry and reduce the number of double bonds.

Biolubricant developers also have another option: genetic engineering. Some plants, such as soybeans, have been engineered to have high levels of oleic acid in the oil molecule. High-oleic soybean oils—which Honary says were developed for frying foods—naturally resist oxidation, reducing the amount of chemical processing and additives they require. Oil from genetically modified (GM) soybeans patented by DuPont contains more than 83% oleic acid, whereas conventional soybeans contain about 18%, Honary says.

According to tests conducted by the ABIL group, high-oleic soybean oil lasts much longer than conventional soybean oil or canola oil. When aged artificially in a test apparatus, unprocessed soybean oil lasted the shortest length of time. Canola oil and chemically modified soybean oil each lasted approximately 5 times longer than the unprocessed oil, and high-oleic GM soybean oil lasted approximately 27 times longer.

Although less chemical processing may mean a less expensive fluid, that doesn't necessarily mean that high-oleic oils save money. "We don't use [GM soybean oil] in production for several reasons," Erhan says. One reason is that the price of GM soybean oil is high. That's because the seeds are expensive, and farmers must buy new seeds every year rather than harvest them at the end of the season. Currently, Erhan says, the processing savings don't offset GM soybeans' higher cost.

"The guys who are selling high-oleic oil are commanding a premium that's above the market value," adds Mark Miller, a chemical engineer who heads Terresolve Technologies, an Eastlake, Ohio–based manufacturer of biolubricants. "I can chemically enhance my refined, bleached, deodorized commodity oil to meet the performance of a high-oleic for less money."

Perhaps more promising, Erhan says, is the potential to selectively breed soybeans that are naturally higher in oleic acid. Currently no non-GM high-oleic soybeans exist. But the Better Bean Initiative—directed by the Technology Utilization Center of the United Soybean Board, a nonprofit industry group—has a goal of developing a reduced *trans* fatty acid, low-saturate, and thus heart-friendly soybean oil through selective breeding, with food applications as its target market. Although these soybeans may not be as high in oleic acid as GM beans, they would be higher than current soybeans, Erhan says.

Similarly, Honary says, other new types of oilseeds may be developed for industrial oils. One good candidate, he says, is seed from meadowfoam, a winter annual that is native to northern California and southern Oregon. Because meadowfoam oil contains long-chain fatty acids that have high levels of monounsaturation and very low levels of polyunsaturation, it is stable when heated, and it doesn't oxidize easily. Currently, however, very little meadowfoam is grown commercially.

Slipping into the Market

Like petroleum-based fluids—which since the start of the Industrial Revolution 200 years ago have evolved to fill many narrow niches—biobased fluids must be honed for specific applications. Most of the markets that biolubricant manufacturers are targeting are those in which the reduced environmental impacts of the plant products help justify their higher costs, says Skip Hauth, executive director of the nonprofit Center for Bioindustry Development in Grand Island, New York. And, he says, these benefits must be real rather than just perceived.

"If you look at the demographics," Hauth says, "typically what you find with these kind of specialty products is that you can engage somewhere in the range of five to eight percent of the marketplace based on the 'feel-good' issues. I think that number is going to rise as people start sitting back and saying, 'Gee, would I pay a little bit more if I knew that it was better for me and better for the air and better for the environment?'"

The rest of the engagement of the marketplace in the short term is all based on performance and price, Hauth says. At some North American electrical utilities, for example, at least two highly specialized biobased fluids—wicket gate grease and transformer oil—have started to penetrate this traditionally conservative business sector.

In hydroelectric dams, grease is applied to the gates that control the flow of water to the turbines. The bushings on these "wicket gates" are exposed to a regular flow of water that inevitably washes away lubricating grease that—in traditional petroleum-based products—can contain lead, phosphorus, lithium, and benzene compounds, says Ken Brown, an engineer for Utility Service Associates, a consulting company in Toronto, Canada.

To keep these pollutants out of the waters below dams, Utility Service Associates developed and markets a food-grade canola-based grease called Cor-Tek VSG that is biodegradable and free of heavy metals, and, Brown says, that outperforms petroleum greases. “Because [Cor-Tek VSG] is a better grease than most people are using, even though it costs a bit more, people have found that they’ve been able to use much less,” he says. “So even on just straight cost, without taking into account the environmental aspects, it comes out even less expensive.”

So far, Brown says, many companies have declined to adopt the grease due to “systemic roadblocks,” the result of bureaucracy and regulations that do not distinguish between persistent and readily biodegradable oils. However, at least two Canadian utilities and the U.S. Department of the Interior Bureau of Reclamation (in operating Parker Dam in California) do use it.

Change has come somewhat more quickly for biobased transformer oil. Utilities across the country have installed transformers filled with bio-oil, and two—the Sacramento Municipal Utility District (SMUD) and Waverly Light and Power in Iowa—are installing only transformers that are filled with bio-oil.

Oil in a transformer doesn’t lubricate; it cools and insulates. Small transformers, such as the ones found in stereo systems and consumer electronic devices, don’t need to use oil because they can disperse the modest amounts of heat that is generated when electricity passes through their coils. But large industrial transformers handle lots of power and so are cooled using anywhere from a few to several hundred gallons of oil per transformer.

If this oil spills from the transformer—say, when a utility pole is hit by a car or a lightning strike sets a transformer on fire—the environmental damage can be substantial and expensive. According to Glenn Cannon, general manager of Waverly Light and Power and one of the developers with Honary’s group of a transformer bio-oil now marketed by Cargill, one 20-gallon spill cost the utility $27,000 to clean up.

Another hazard is posed by the use of polychlorinated biphenyls (PCBs) as insulators in transformers. As of 1994, according to the U.S. Environmental Protection Agency, about 200,000 American transformers still used oil that contained PCBs. Although PCB use in the United States has been banned since 1979, the use of existing PCB-containing equipment is permitted. As this equipment continues to age, the agency says, the risk of failure and thus releases to the environment increases. PCBs, which bioaccumulate and bioconcentrate, can cause the disfiguring skin disease chloracne, liver damage, nausea, dizziness, eye irritation, and bronchitis in humans. In laboratory animals, PCBs have caused reproductive problems, gastric disorders, skin lesions, and cancerous tumors.

Reducing remediation costs is just one reason that SMUD committed to installing more than 10,000 transformers filled with about 680,000 gallons of bio-oil over the next four years, says Mike Rudek, SMUD’s process coordinator for distribution design and standards. Bio-oil is also safer. “The new fluids have a much higher flash and fire point,” he says. “Transformers filled with the new fluid are considered to be less flammable, which means that they don’t support the fire; they don’t continue to burn if they do catch fire.” And, he says, SMUD’s customers, living in California where the environment is a hot topic, are especially sensitive to environmental issues. But ultimately, he says, the utility justified switching to bio-oil, which costs 2–3 times as much as petroleum oil’s $3–5 per gallon, because they estimated that the oil will make the transformers last about 25% longer, stretching their time in service from 30 years to 40.

“It appears as though the lifetime of transformers can be significantly enhanced if you use a vegetable-based transformer oil relative to a mineral-based transformer oil,” says Brent Aufdembrink, Cargill’s global technology manager for industrial oils and lubricants. That’s because the transformer’s paper insulation lasts longer, says John Luksich, a senior engineer specializing in dielectric fluids at Cooper Power Systems in Waukesha, Wisconsin.

The insulation is a special cellulose polymer that breaks down by hydrolysis, which requires heat and water. Because vegetable oils are much more polar than petroleum oils, they can draw moisture from the paper, which slows its aging. In tests that Cooper Power Systems conducted on its Envirotemp FR3 dielectric fluid, which were presented at the 2001 Institute of Electrical and Electronics Engineers/Power Engineering Society Transmission and Distribution Conference, kraft paper (like the paper used in transformer insulators) took 5–8 times longer with Envirotemp than with conventional oil to deteriorate to the point at which it no longer served as an effective insulator.

Honary says the ABIL research group is working with Environmental Lubricants Manufacturing, a commercial entity spun off from the research group, and holds exclusive rights to develop DuPont’s GM soybean oil for commercial fluids. The group has developed two dozen highly stable biobased lubricants from this soybean variety.

Sliding Home

No matter what the product, biofluids will still have to outperform petroleum-based rivals in the U.S. market. “If we [producers] are going to charge more money for our fluids—and we really have to because the oils are more expensive and the additive chemistry is more expensive—we have to show a value to the consumer,” Hauth says. “We also have to clearly demonstrate its performance capabilities.”

Market acceptability, a primary focus of the ABIL research group, got a boost this year when the Norfolk Southern Corporation, one of four Class I railroads utilizing the majority of U.S. rail curve greases, switched their entire operation to ABIL-developed soy grease. The Crete Carrier Corporation, estimated to be the sixth-largest trucking firm in the country (inclusive of its affiliated subsidiaries), also began a companywide conversion to soy grease developed by the ABIL group. Honary believes acceptance of these products is due to the fact that new technologies are finally allowing biobased products—at least in selected niche areas—to outperform conventional products and to be economically competitive with petroleum-based lubricants.

Scott Fields

Suggested Reading

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